weeks, its behavior has not yet been studied at all thoroughly. We have been able to obtain a focussed beam of ions of 20 to 50 microamperes. These currents were measured with a Faraday cage, a magnetic field trapping secondary electrons. Checking by the disintegration yield from LiF bombarded at 250 kv showed that they must be largely protons. Under these circumstances the total current drawn from the arc was a little over one milliampere and the arc current itself was of the order of 0.2 amperes.

The source is a low voltage arc of the general form described by Lamar and Luhr,[1] with certain alterations suggested by Mr. Eugene W. Pike of this laboratory. Power supply for it and the associated solenoid is obtained from an aircraft radio generator driven by an insulating textolite shaft. The arc consists of an oil-cooled copper cylinder $2\frac{1}{2}''$ long and $1\frac{1}{2}''$ in diameter which is the anode, with a cylindrical oxide-coated cathode along its axis. The ends are closed by copper disks insulated from the cylinder by lavite rings. The end-plates are held slightly negative with respect to the cathode, the protons escaping through a $1/8''$ hole in the center of one plate while hydrogen is admitted through a tube fastened to the opposite end.

The whole is placed inside a solenoid which produces a field of about 400 gauss along the axis, sufficient to keep electrons from reaching the anode without making one or more collisions. The solenoid, wound with No. 10 enameled wire, is placed directly in the main vacuum tube and seems to give no trouble when 6 to 8 amperes flow through it. In some preliminary work at pressures of hydrogen as low as 5×10^{-3} an arc current of one ampere was obtained, the drop between anode and cathode being about 35 volts. At somewhat lower pressures the arc current drops sharply and the voltage rises, although the ion current does not seem to change as rapidly.

It seems possible that with better focussing conditions, which would bring a larger percentage of the ions leaving the arc to the target, currents of a considerable fraction of a milliampere may be obtained fairly easily.

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March 14, 1934.

[1] Lamar and Luhr, Phys. Rev. **45**, 287 (1934). We are indebted to Dr. Lamar for communicating to us the details of this source before publication.

Disintegration of Boron by Deutons and by Protons

Using a method we have already described in some detail,[1] we have attempted to analyze the radiation obtained from boron bombarded with a mixed beam of deutons and protons. The absorption of the radiation in lead and in paraffin out to a thickness of 8.3 cm was measured by using both a lead and a paraffin lined ionization chamber. The four curves obtained are shown in Fig. 1. The large absorption obtained with small thicknesses of lead, when using a lead lined chamber (see curve IV), shows clearly that, in addition to neutrons, there is a large component of γ-radiation. The dotted line in this, as in our previous work, represents the intensity due to neutrons alone, as obtained by extrapolation, and the difference between this and curve IV is ascribed to γ-rays. The γ-ray intensities thus obtained are plotted on a log scale in Fig. 2, together with a curve obtained with a radium γ-ray source under the same conditions for comparison. The curve for the boron γ-rays is a straight line having the same slope as the curve for radium after 1.5 to 2.0 cm of lead filtration. It must therefore be concluded that the quantum energy of the γ-rays from boron here observed is close to 1.6×10^6 e.v. By comparing the intensity of the boron γ-radiation with that of the radium, we were able to determine the number of quanta produced per second. This checks with the number of neutrons, to within the accuracy with which we are able to estimate the number of neutrons from the ionization they produced in the paraffin lined chamber. It is probable, then, that the γ-rays are associated with the same transformation

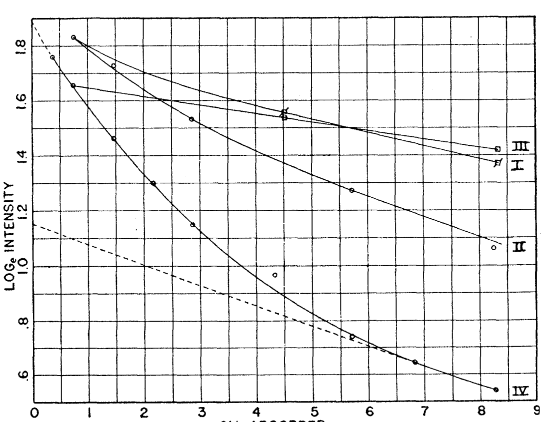

Fig. 1. Absorption of the boron-H^2 radiation. I, paraffin chamber, paraffin absorber: II, paraffin chamber, lead absorber; III, lead chamber, paraffin absorber; IV, lead chamber, lead absorber.

[1] Crane and Lauritsen, Phys. Rev. **45**, 226 (1933).

γ-rays and neutrons in approximately equal numbers were obtained from beryllium bombarded with deutons. Due to an error in plotting the absorption curve for the γ-rays, the absorption coefficient appeared to be only one-half its real value. After correcting this, and making a small correction for scattering, the linear absorption coefficient comes out to be 1.2, corresponding to a quantum energy of about 0.7×10^6 e.v. This energy probably corresponds to an excitation level in the B^{10} nucleus.

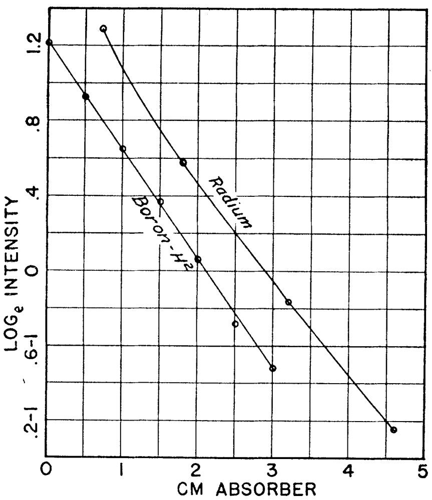

FIG. 2. Absorption of the boron γ-radiation in lead with the absorption of radium γ-radiation made under the same experimental conditions for comparison.

which produces the neutrons, which we assume to be

$$B^{11}+H^2 \rightarrow C^{12}+n^1+\gamma, \quad (1)$$

and that 1.6×10^6 e.v. corresponds to an excitation level in C^{12}.

The relative efficiency of production of the radiation from boron as a function of the energy of the deutons was investigated, and is shown in Fig. 3. An ion current of 10 microamperes was used—approximately 3 microamperes due to deutons—and at 900,000 volts we estimate that about 2×10^6 neutrons (and an equal number of γ-ray quanta) per second were being produced.

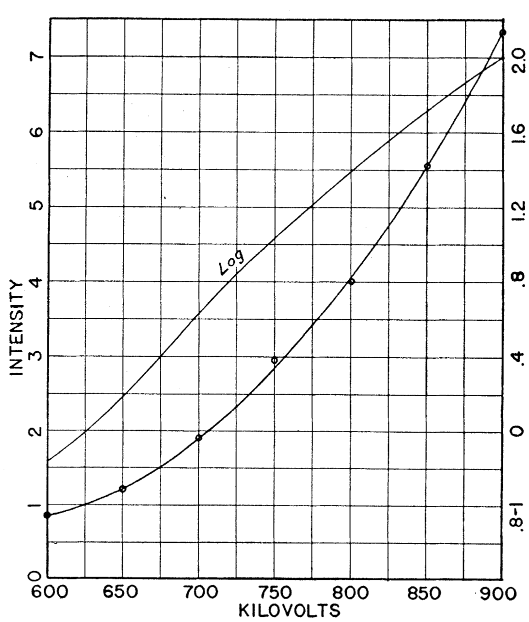

FIG. 3. Intensity for boron radiation as a function of the voltage used to accelerate the deutons.

Since the ion beam used consisted of at least as many protons as deutons, it seemed desirable to determine whether or not protons were responsible for any of the effect observed. In particular, γ-rays might be expected to accompany the α-particles produced in the disintegration of boron by protons on the basis of the work reported by Oliphant and Rutherford.[2] They assumed the reaction

$$B^{11}+H^1 \rightarrow 3He^4 \quad (+11\times10^6 \text{ e.v.}), \quad (2)$$

and treated the problem on the assumption that the α-particles of maximum energy represent those cases in which one of the α-particles gets 2/3 of the total energy, or in other words the cases in which two of the particles go off in one direction with equal energies, and the third in the opposite direction. On this hypothesis the maximum range they observed gave only 9×10^6 e.v. total energy for the three α-particles, or 2×10^6 e.v. less than expected from the energy balance in the above equation. This then might indicate a γ-ray quantum corresponding to that energy.

To test this possibility, boron (B_2O_3) was bombarded with 10 microamperes proton current at 900,000 volts, but no γ-rays were found, and the effect, if present at all can be said to be less than 1/50 that to be expected if there were one γ-ray quantum per disintegration.

It is natural, in view of this result, to consider the possibility of there being some restriction on the angles at which the three α-particles may be ejected with respect to one another, and that the case in which one of the particles gets 2/3 of the total energy may be excluded. This seems understandable if we reason as follows: As long as the three α-particles are so close together that they do not repel each other with the known Coulomb forces, we can say nothing of the way in which the energy is distributed among them. However, after they become separated far enough to repel each other according to the Coulomb law, they will still have considerable potential energy with respect to one another. It is known from experiments on the scattering of α-particles in helium that the inverse square law of force holds down to distances corresponding to potentials of the order of a million e.v. This means that, after complete separation, the relative velocity between any pair of the three particles resulting from the disintegration of the boron nucleus must correspond to the conversion of at least a million e.v. of potential into kinetic energy and that the case of two of the particles coming off in the same direction is ruled out. Taking Oliphant and Rutherford's value (5.96×10^6 e.v.) as the maximum observed energy of the α-particles, and 11×10^6 e.v. as the total energy available, the minimum kinetic energy any two α-particles can have with respect to each other is 2×10^6 e.v., an altogether reasonable figure, on the basis of the above argument. All this is on the assumption that the nucleus does break up into three separate

[2] Oliphant and Rutherford, Proc. Roy. Soc. **A141**, 259 (1933).

α-particles, and that two of them do not remain permanently associated together as in Be^8.

Since the discovery by Curie and Joliot of the delayed decomposition of some of the products of artificial transformations, we have observed such an effect from a target of B_2O_3 after deuton bombardment. A target of SiO_2 was also bombarded and no effect of comparable intensity was observed, so it is quite certain that the effect obtained with B_2O_3 is due to the boron. This means that in addition to the process described above, another process must take place to form a radioactive substance, and we suppose that the reaction is

$$B^{10}+H^2 \rightarrow C^{11}+n^1, \qquad (3)$$

the C^{11} being the radioactive product. From a comparison of the intensities of the two effects, we estimate that reaction (1) takes place about 200 times as frequently as reaction (3). Since there is only one-fifth as much B^{10} in the target as B^{11}, we may say that the ratio of the probabilities of reaction (1) and (3) taking place is about 40 to 1.

It is a pleasure to acknowledge our indebtedness to the Seeley W. Mudd Fund for the support of this work.

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March 13, 1934.

Errata:—The Mass of the Neutron and the Stability of Heavy Hydrogen

(PHYS. REV. **45**, 224, 1934)

Professor Uhlenbeck has kindly drawn my attention to the fact that there is a mistake in the value given in my former letter for the upper limit of the mass of the neutron when calculated from the production of neutrons by bombarding Li with α-particles. If one assumes the kinetic energy (k.e.) of the neutrons to be zero, the k.e. of the recoil B nucleus comes out as 0.0022_4 (in mass units) and the neutron mass as 1.0067 (instead of 1.0093); if one puts the k.e. of the neutrons equal 0.0005, the k.e. of the recoil B nucleus comes out as 0.0012_6 and the neutron mass as 1.0072, i.e., equal to the proton mass.

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March 10, 1934.

Excitation and Disintegration of Protons and the Neutret

The gamma-rays produced in experiments of Lea[1] by bombarding hydrogen with neutrons, can be explained by a mechanism which has advantages over those suggested by Lea[1] and Auger.[2] It may be supposed[3] that under special conditions a proton may be decomposed into a neutron and a positive electron. Moreover as Auger[2] has remarked there may be excited states of the proton where the positive electron may be thought of as occupying a higher energy level than in the normal state. The excitation process would be peculiar in that a change from Fermi to Bose statistics would be involved. This difficulty embarrasses all theories which do not consider the proton and the neutron to be elementary particles. Tentatively the interaction between neutron and positive electron must be regarded as non-electromagnetic. In such case not only would the transition from an excited to the normal state be forbidden by an almost rigorous selection principle because of conservation of momentum, but also transitions between excited states with emission of photons would also be unlikely because there is no coupling with the electromagnetic field. The present problem is apparently closely related to the difficulty of continuous β-ray spectra. It seems to the writer that even if the difficulty cannot be resolved by quantum mechanics in the present form it is legitimate to make use of the implications of the difficulty in the manner of this note.

A valence electron around such an excited proton could, without violating a selection principle, annihilate the excited positive electron and leave a neutron and a photon. Taking the mass of the neutron to be 1.0062[4] the energy of the photon would be equivalent to 1.5 million volts plus the excitation energy of the proton. Thus the radiation observed by Lea could be explained easily.

A natural step from the preceding argument is the idea of spontaneous disintegration of the excited proton. The normal proton has more energy than a neutron and a positive electron but presumably cannot break up because of the selection principle already mentioned. In the long lived excited state the transition to the normal state is forbidden and therefore the disintegration is not. This may be an interpretation of the long continued emission of positive electrons observed by Curie and Joliot[5] after α-ray bombardment of certain substances. Indeed the mechanism involving intermediate products such as N^{13} is unnecessarily indirect and involves the emission of a neutron from nuclei known to be capable of expelling a proton. A further application of the suggestions of this article is to the production of various γ-rays by transitions between excited proton levels. At this point a serious

[1] D. E. Lea, Nature **133**, 24 (1934).

[2] P. Auger, Comptes Rendus **198**, 365 (1934).

[3] R. M. Langer, Science **76**, 294 (1932); I. Curie and F. Joliot, Comptes Rendus **196**, 1885 (1933).

[4] R. M. Langer, Phys. Rev. **45**, 137 (1934). A smaller mass would permit still more energy.

[5] I. Curie and F. Joliot, Comptes Rendus **198**, 254 (1934).